

# Ferrite/Ferroelectric Multilayers for Constant Impedance Frequency Agile Microwave Devices

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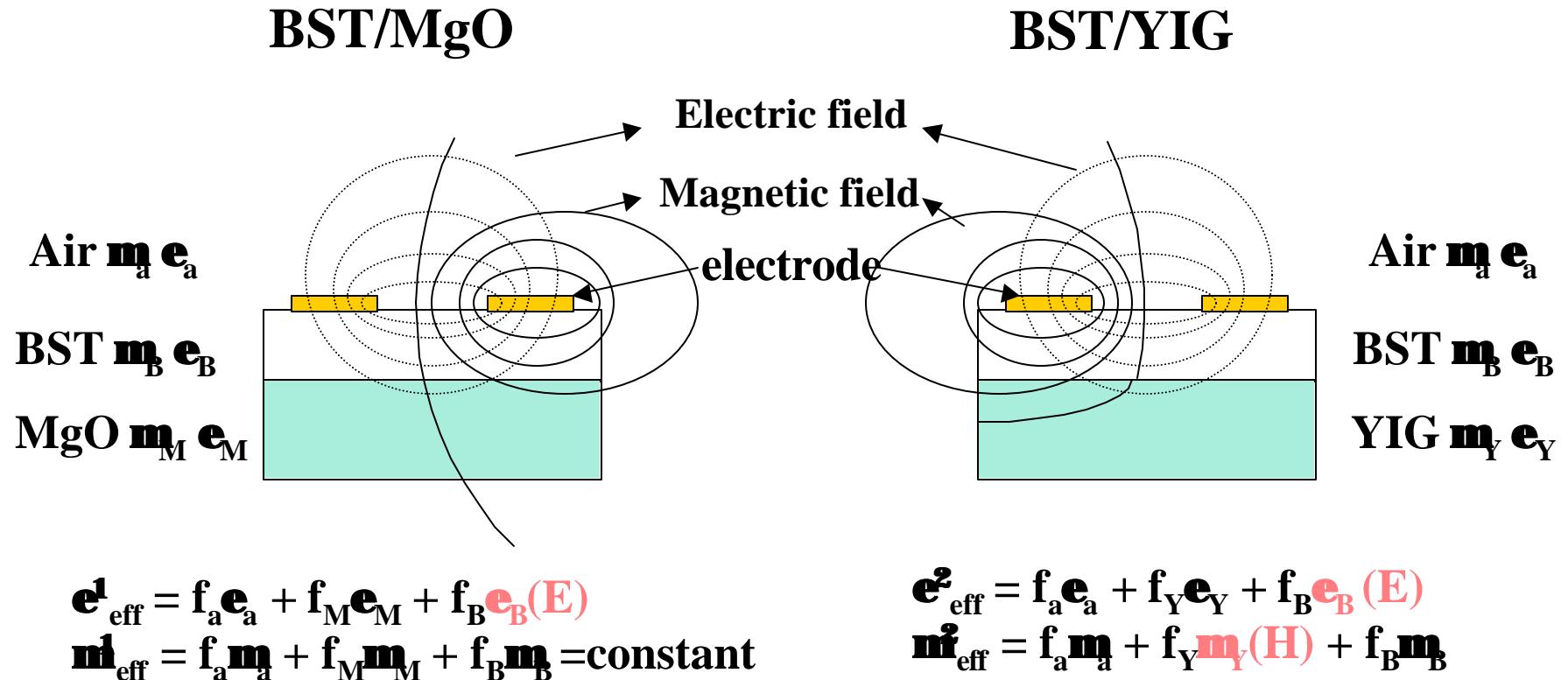
# Abstract

- A concern in the development of ferroelectric based tunable microwave devices is the large change in the characteristic impedance of the device as the dielectric constant is reduced.
- To solve this problem, use a ferroelectric/ferrite multilayer.
- It will be possible to simultaneously tune both permeability of ferrite and dielectric constant of ferroelectric by applying magnetic and electric fields, respectively.

# Results

- $(\text{Ba},\text{Sr})\text{TiO}_3$  (BST) thin films have been deposited by pulsed laser deposition (PLD) onto single crystal  $\text{Y}_3\text{Fe}_5\text{O}_{12}$  (YIG) substrates.
- The structure of BST/(MgO)/YIG multilayer films have been characterized using XRD and cross-section TEM.
- For BST/(100)YIG, polycrystalline BST films have a high tunability ( $\sim 40 \%$ ) with dc bias and dielectric Q's between 30 and 40, while (100) oriented films have a lower tunability ( $\sim 20 \%$ ) but higher dielectric Q ( $\sim 50$ ).
- Co-planar transmission lines fabricated on BST/(111)YIG exhibit  $13.5^\circ$  differential phase shift with an applied dc bias voltage of 27 V or with an applied magnetic field of 85 Guass.

# Dielectric or Ferrite Substrates



$$\text{Group velocity of microwave } v_g = (\epsilon_{\text{eff}} \mu_{\text{eff}})^{-1/2}$$

# Ferrite/Ferroelectric multilayers

Phase shift ( $\Delta\phi$ ) can be calculated by  $\Delta\phi = \frac{2\mu f}{c} l (\sqrt{\epsilon_1 m_1} - \sqrt{\epsilon_2 m_2})$

and the impedance ( $Z$ ) is related to,  $Z_o \propto \sqrt{\frac{m}{\epsilon}}$

$\Delta\phi$	$\epsilon=1$	$\epsilon=10$
$\mu=1$	0	$1-\sqrt{10}$
$\mu=10$	$1-\sqrt{10}$	$1-\sqrt{100}$

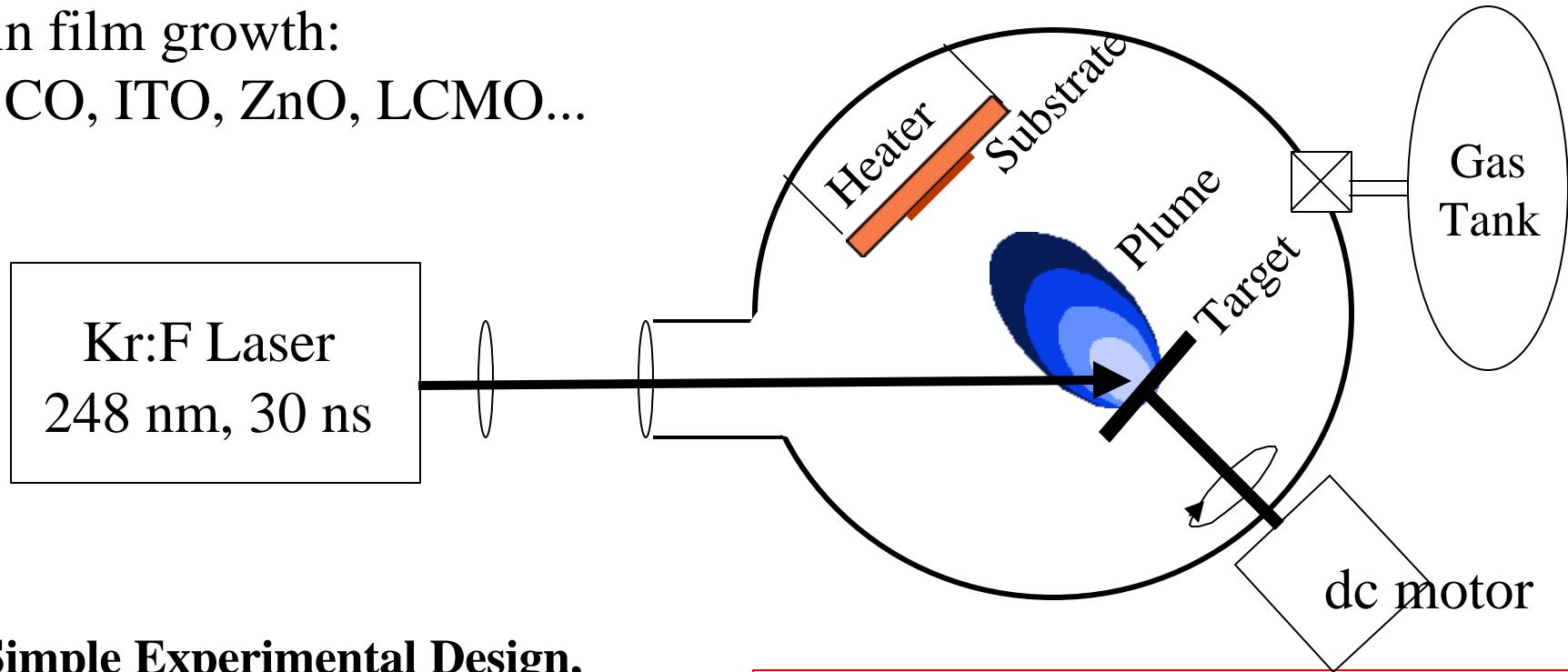
$Z_o$	$\epsilon=1$	$\epsilon=10$
$\mu=1$	$Z_o$	$Z_o / \sqrt{10}$
$\mu=10$	$\sqrt{10} Z_o$	$Z_o$

We can tune dielectric constant of ferroelectric (BST) and permeability of ferrite (YIG) at the same time using electric and magnetic field, respectively, while the characteristic impedance ( $Z_o$ ) of the transmission line remains constant.

- Need materials with a large change of dielectric constant:  $(\text{BaSr})\text{TiO}_3$
- Need materials with a large change of permeability:  $\text{Y}_3\text{Fe}_5\text{O}_{12}$

# Pulsed Laser Deposition

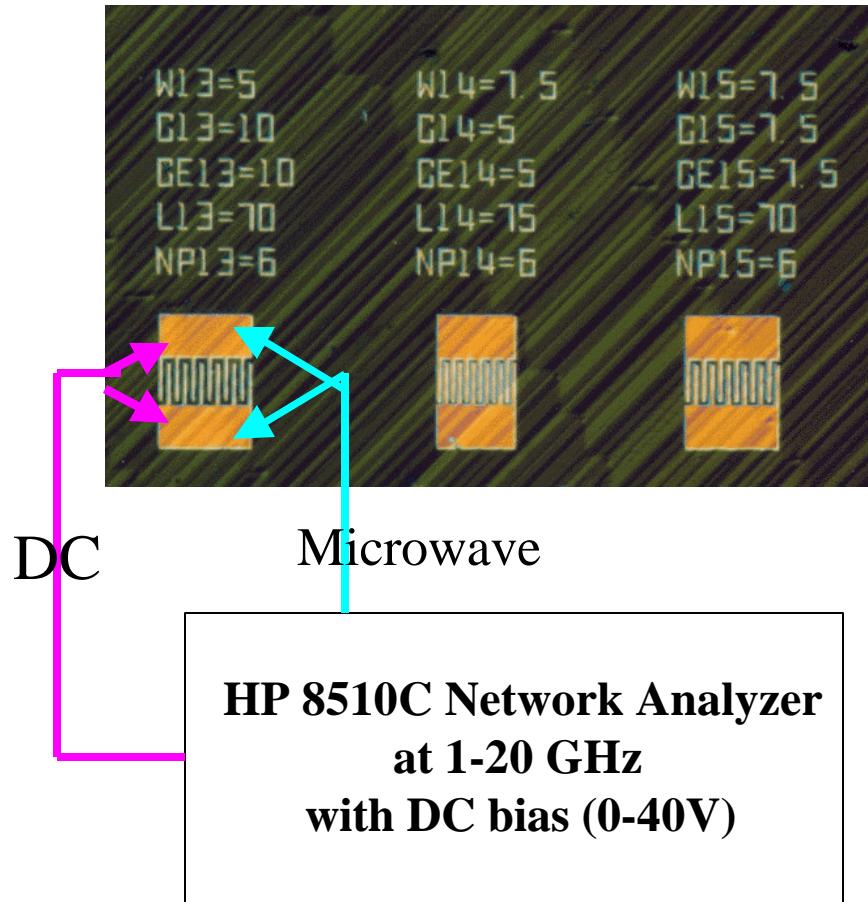
Thin film growth:  
YBCO, ITO, ZnO, LCMO...



- **Simple Experimental Design,**
- **Stoichiometric Transfer,**
- **High Background Pressures of Reactive Gases,**
- **High Reproducibility,**
- **Rapid Production of Smooth Films.**

To optimize microwave properties of BST films:  
Substrate type, Deposition Temperature  
Target composition, Dopant, Post-deposition annealing, Oxygen pressure,  
Laser energy density...

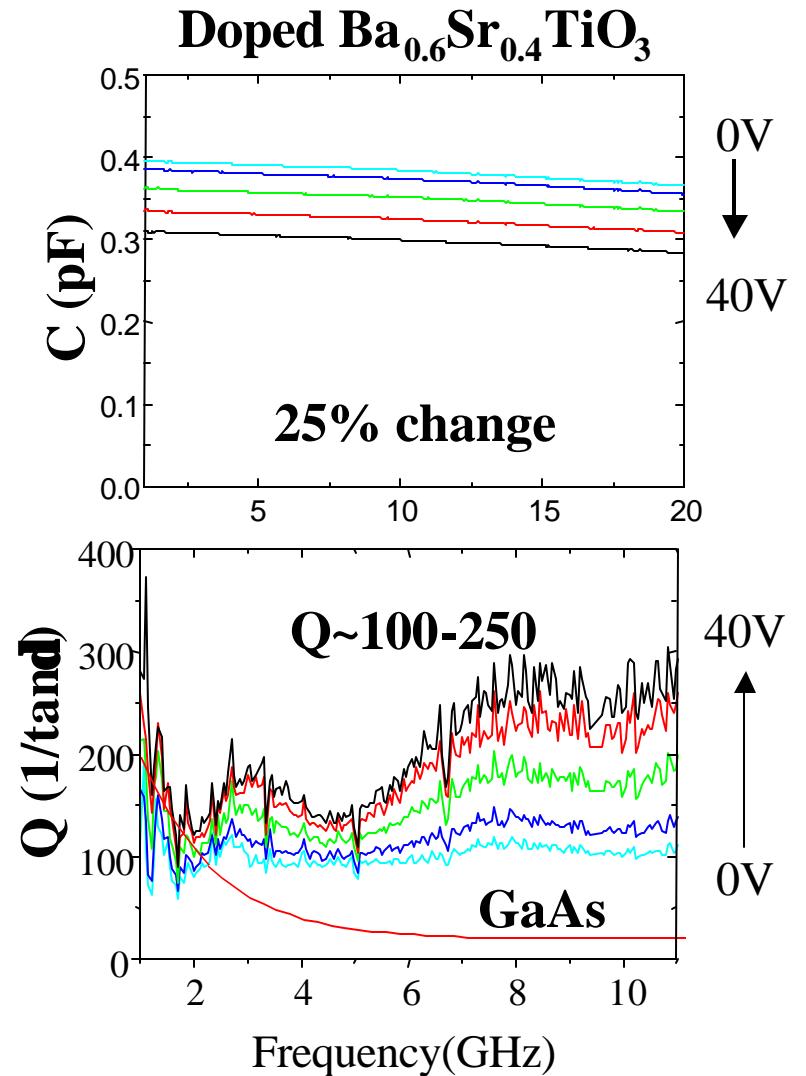
# $\text{Ba}_{0.6}\text{Sr}_{0.4}\text{TiO}_3$ Thin Films



Finger width = 10 mm

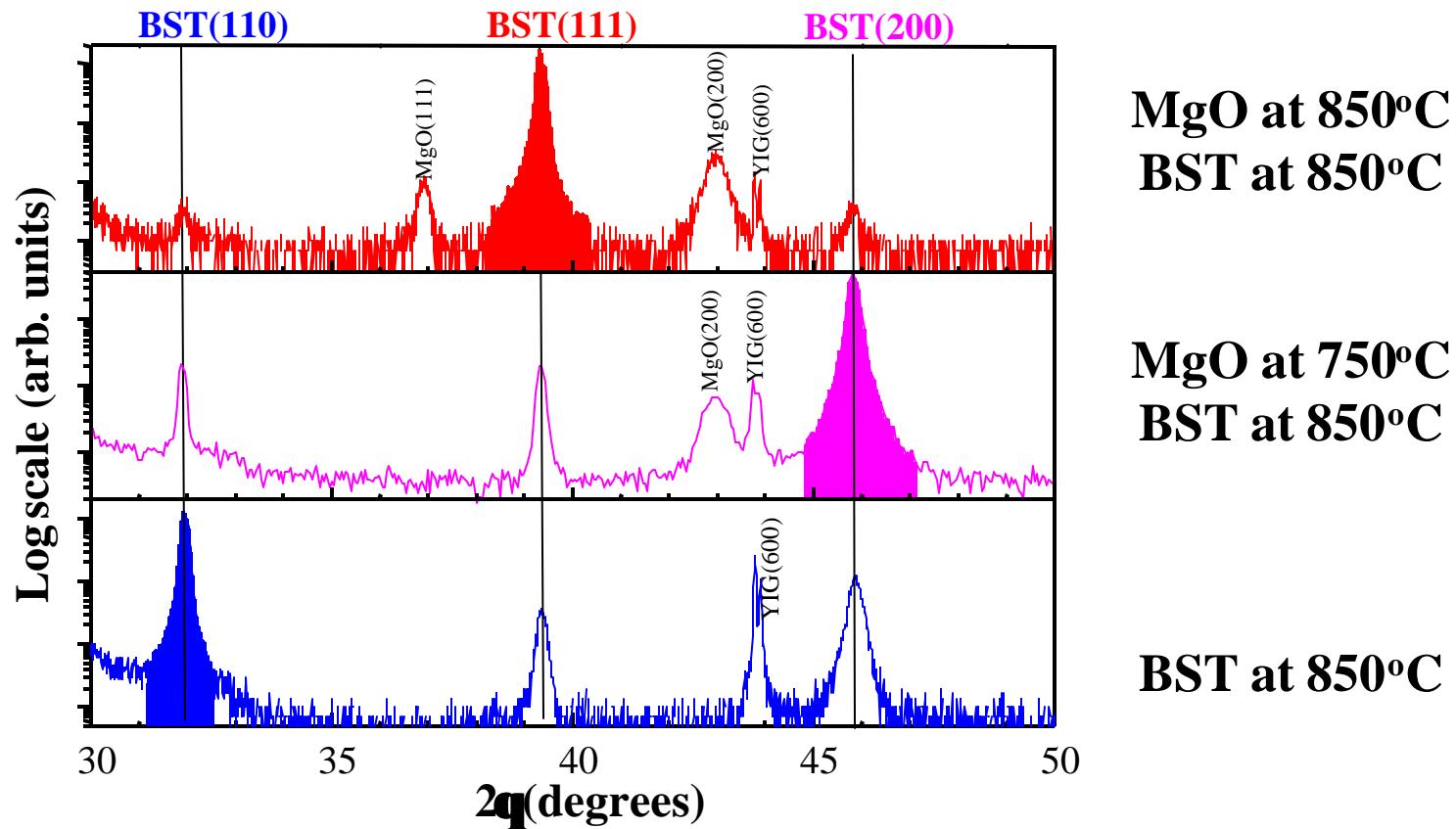
Finger length = 40,60,80 mm

gap = 6, 8, 10,12 mm



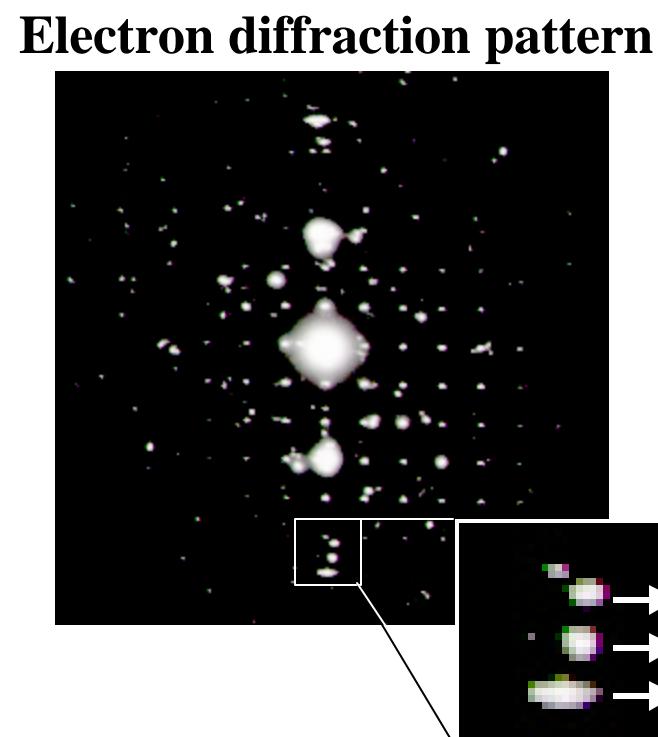
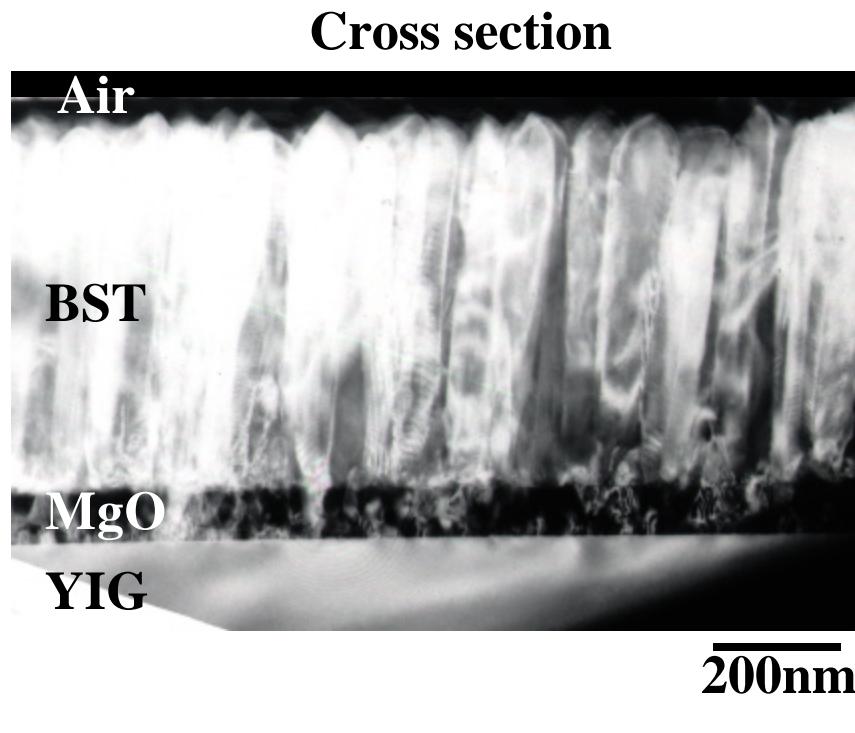
# XRD of BST/MgO/(100)Y<sub>3</sub>Fe<sub>5</sub>O<sub>12</sub> (YIG)

- Large lattice constant difference  $a_{\text{BST}} = 0.3965\text{nm}$  and  $a_{\text{YIG}} = 1.2380\text{nm}$  make it difficult to grow epitaxial BST film on YIG substrate.
- A 100nm MgO ( $a = 0.4211\text{nm}$ ) buffer layer was used.



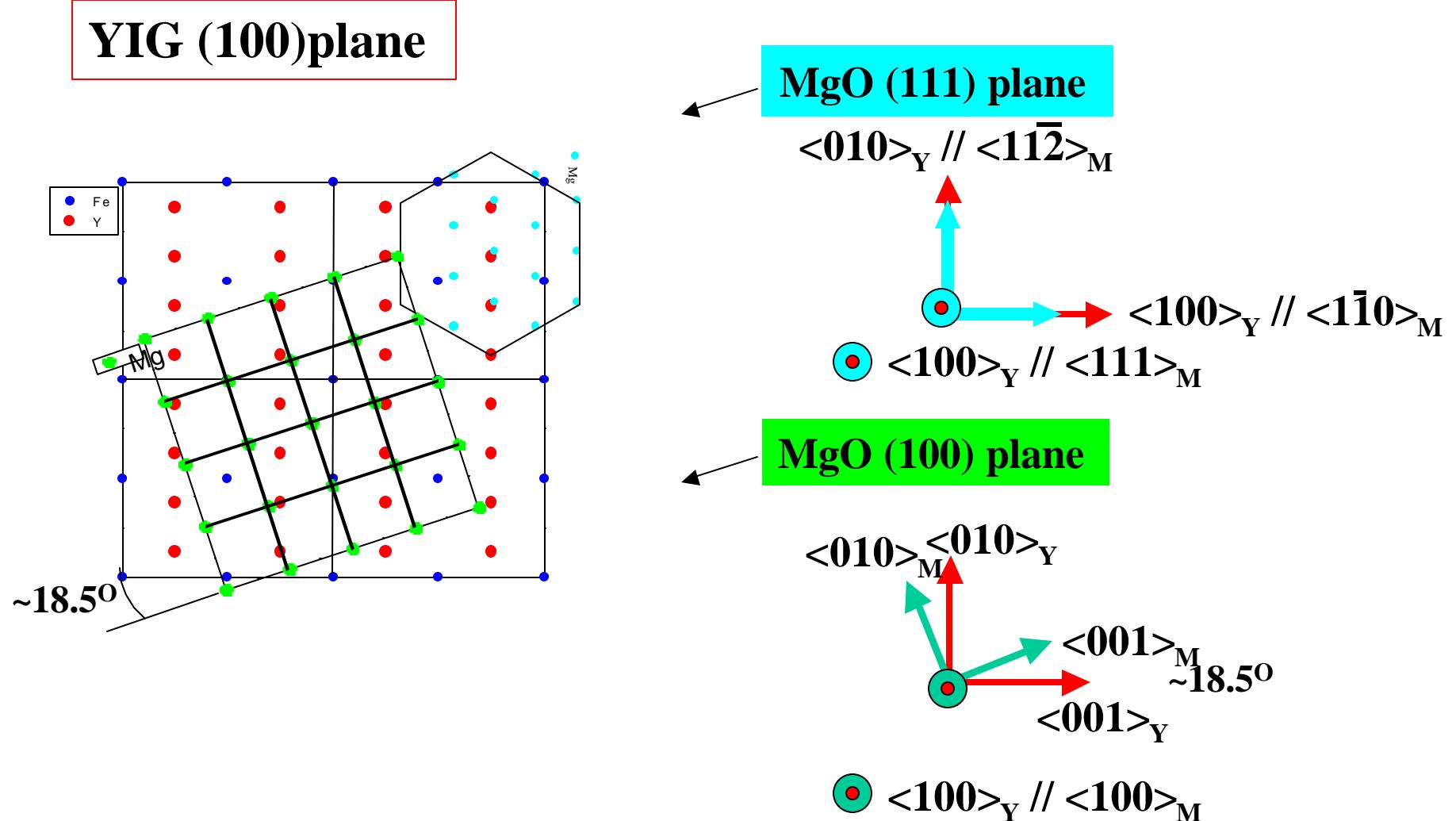
# TEM images of BST/MgO/YIG Multilayer

BST(850°C)/MgO(850°C)/YIG



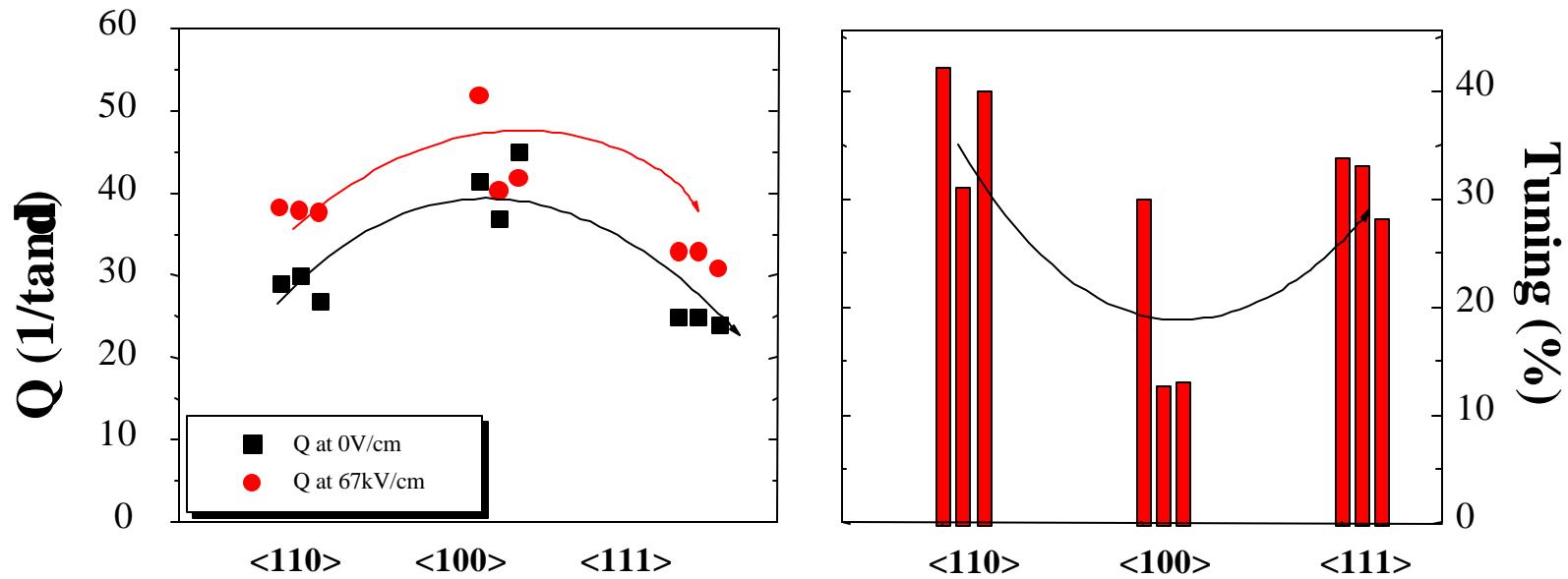
- Width of Columnar grains ~50nm
- Orientation of layers are correlated,  $\langle 100 \rangle_{\text{YIG}} // \langle 111 \rangle_{\text{MgO}} // \langle 111 \rangle_{\text{BST}}$

# Epitaxial BST/MgO/YIG growth



# Microwave properties of BST/MgO/YIG(100)

at 10GHz

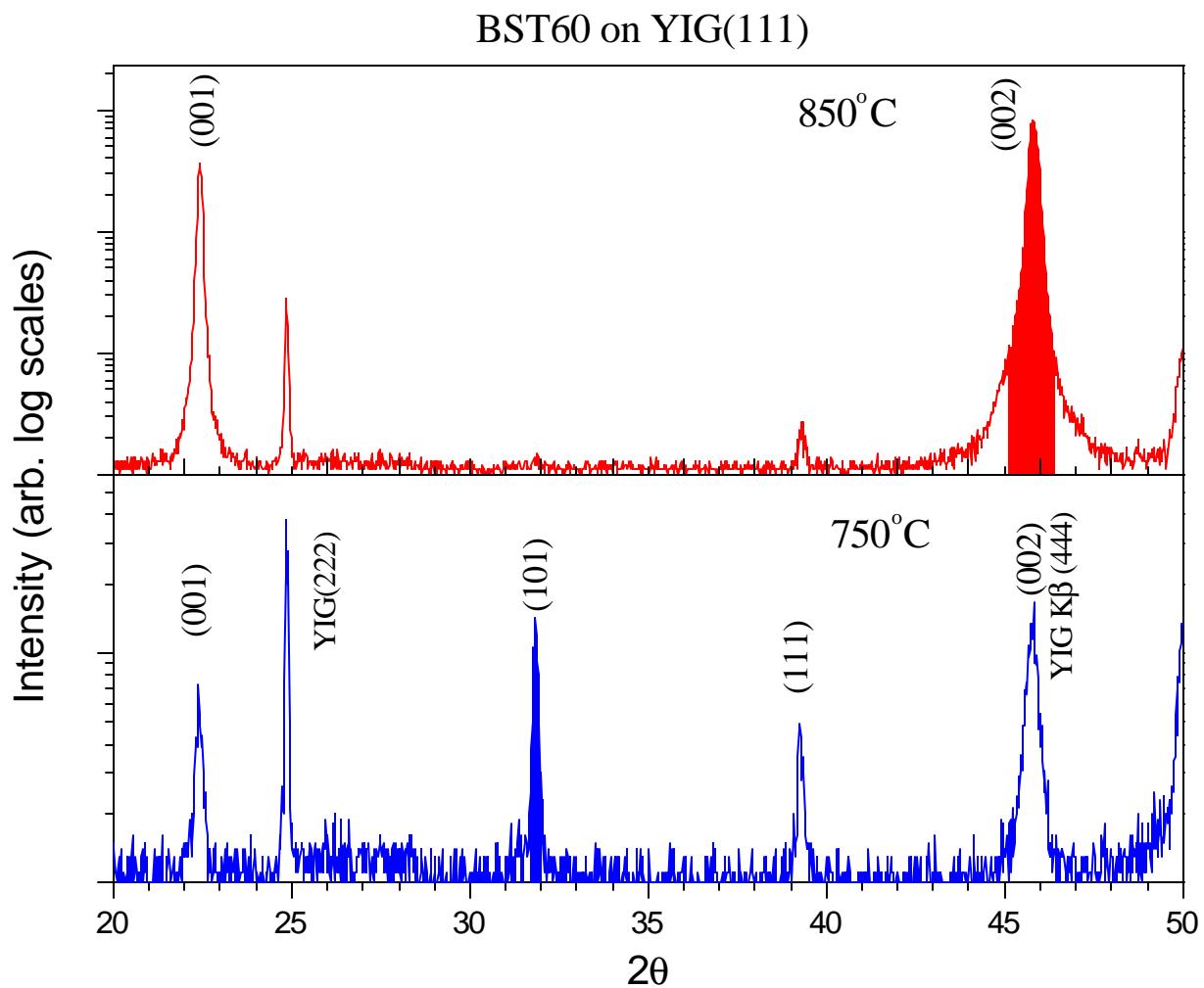


$$Q = 25 - 50, \tan\delta = 0.04 - 0.02$$

$$\text{Tuning \%} = \frac{C_0 - C_h}{C_0} \times 100$$

- $<110>$  textured BST film on YIG shows highest % tuning.
- $<100>$  textured BST film on YIG shows highest Q.

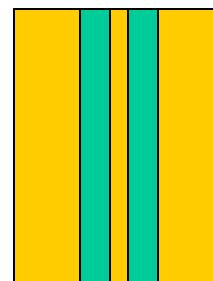
# Effect of Deposition Temperature on BST/(111)YIG



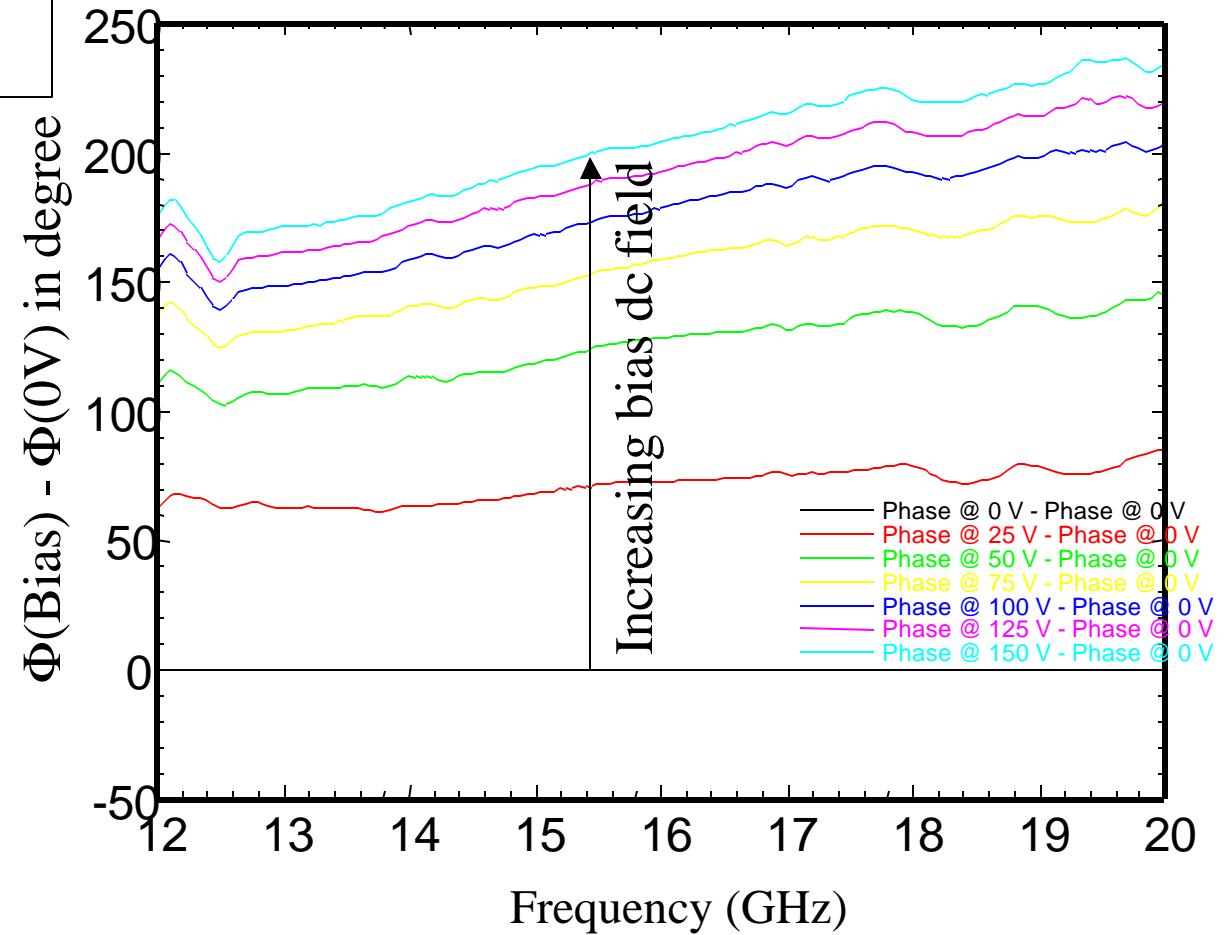
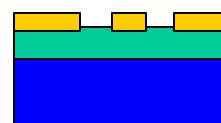
# Coplanar Transmission Line on BST/LaAlO<sub>3</sub>

500nm thick Ba<sub>0.5</sub>Sr<sub>0.5</sub>TiO<sub>3</sub>  
750°C-350mTorr  
annealed at 1100°C

$l=10$  mm,  
gap=16μm,  
width=34μm



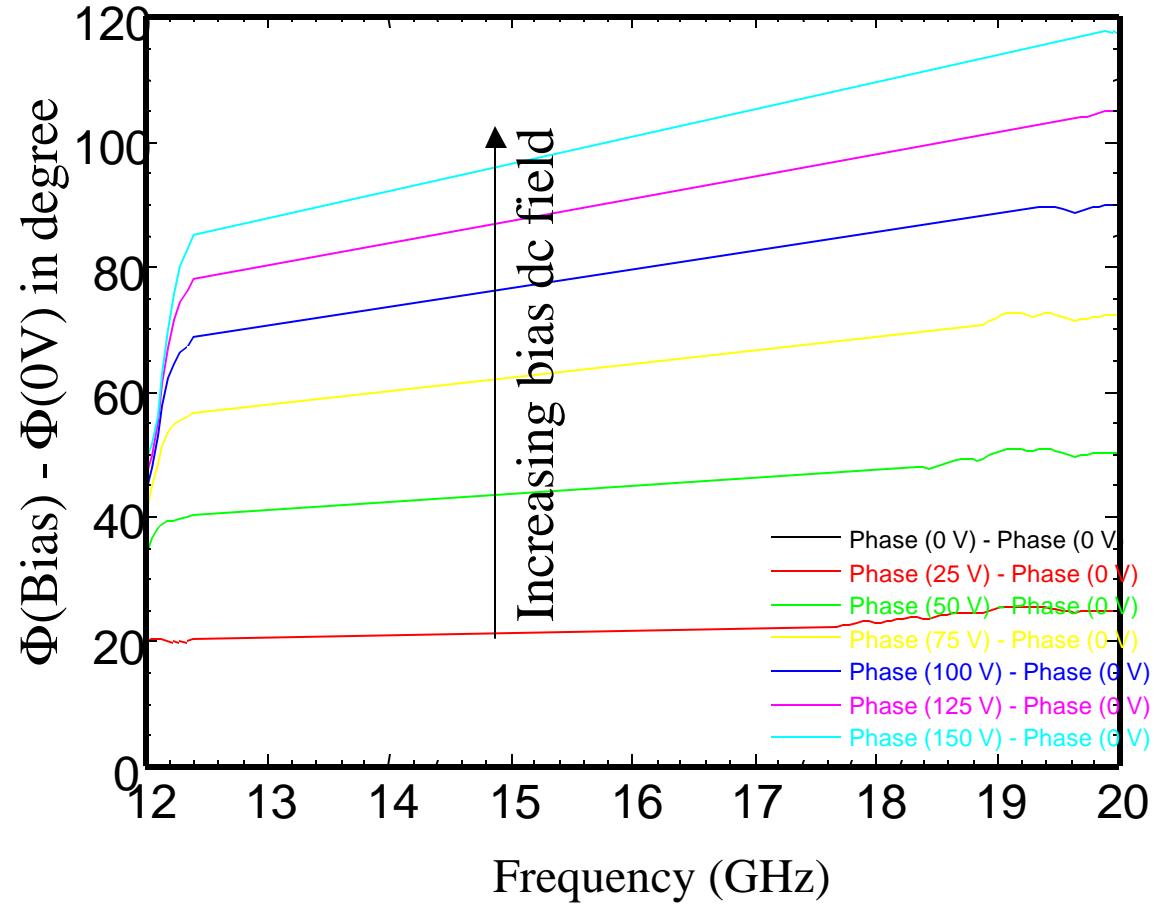
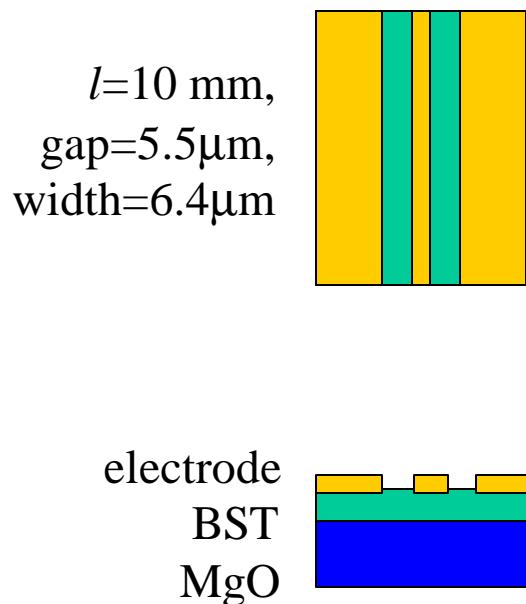
electrode  
BST  
LAO



$\Delta\Phi = 230^\circ$  ( $\Delta t = 32$  ps) with 150V (94kV/cm) at 20GHz.

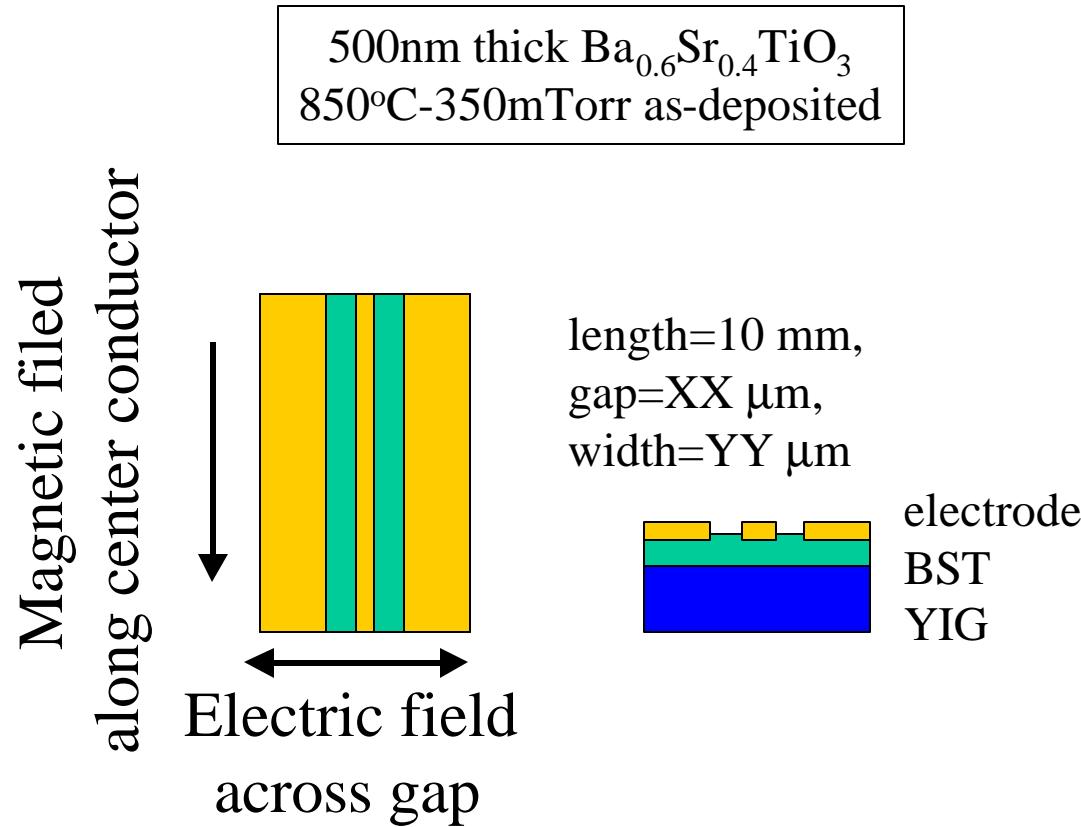
# Coplanar Transmission Line on BST/MgO

500nm thick  $\text{Ba}_{0.6}\text{Sr}_{0.4}\text{TiO}_3$   
850°C-350mTorr  
as-deposited



$\Delta\Phi = 120^\circ$  ( $\Delta t = 17 \text{ ps}$ ) with 150V (270kV/cm) at 20GHz.

# Coplanar Transmission Line on BST/(111)YIG



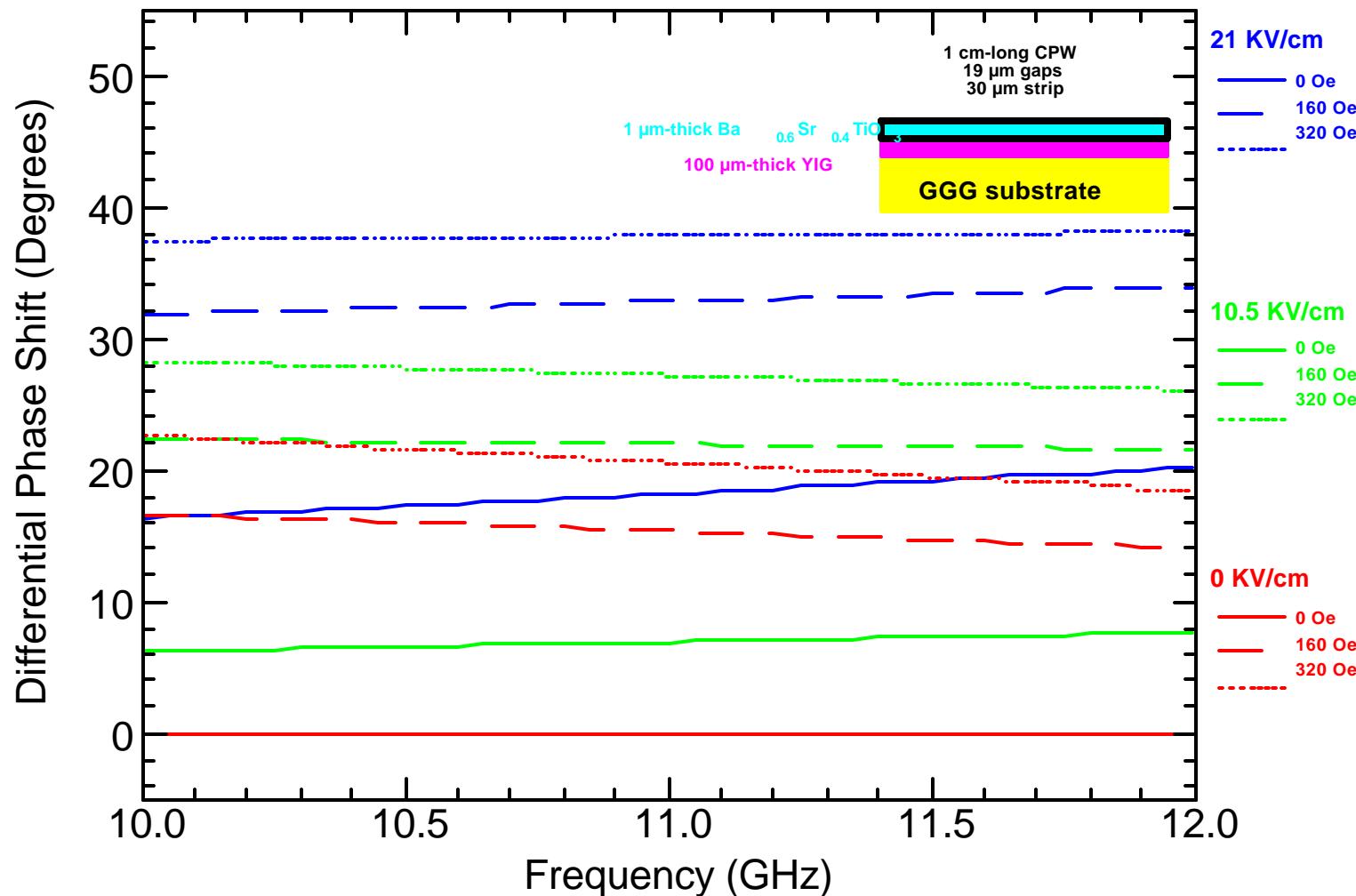
$\Delta\Phi = 13.5^\circ$  ( $\Delta t = 3.5\text{ps}$ ) with 27 V at 10.8GHz.

$\Delta\Phi = 13.5^\circ$  ( $\Delta t = 3.5\text{ps}$ ) with 85 Guass at 10.8GHz.

# Coplanar Transmission Line on BST/(111)/YIG

Electric Field and Magnetic Field Tuning of the Phase Velocity of a Coplanar Waveguide Transmission Line

First Order Behavior of the E-field and B-field Tuning was Determined from a Linear Fit to the Measured Differential Phase Shift Data



# Conclusion

- High quality single phase  $(\text{BaSr})\text{TiO}_3$  thin films were grown on  $\text{Y}_3\text{Fe}_5\text{O}_{12}$  (YIG) substrates by Pulsed Laser Deposition.
- Microwave properties (capacitance and loss) of BST/YIG multilayers were measured using interdigitated capacitors.
- Demonstrated Electric and Magnetic fields dependent phase shifts ( $\Delta\phi$ ) of coplanar transmission lines fabricated on BST/YIG multilayers.